Electric and Magnetic Fields Technical Report
Honolulu High-Capacity Transit Corridor Project

October 1, 2008

Prepared for:
City and County of Honolulu

Preface

This technical report supports the Draft Environmental Impact Statement (EIS) prepared for the Honolulu High-Capacity Transit Corridor Project. It provides additional detail and information as it relates to:

- Methodology used for the analysis
- Applicable regulations
- Results of the technical analysis
- Proposed mitigation
- Coordination and consultation (as appropriate)
- References
- Model output (as appropriate)
- Other information/data

As described in the Draft EIS, the Locally Preferred Alternative, called the “Full Project,” is an approximate 30-mile corridor from Kapolei to the University of Hawai‘i at Mānoa with a connection to Waikīkī. However, currently available funding sources are not sufficient to fund the Full Project. Therefore, the focus of the Draft EIS is on the “First Project,” a fundable approximately 20-mile section between East Kapolei and Ala Moana Center. The First Project is identified as “the Project” for the purpose of the Draft EIS.

This technical report documents the detailed analysis completed for the Full Project, which includes the planned extensions, related transit stations, and construction phasing. The planned extensions and related construction planning have not been fully evaluated in the Draft EIS and are qualitatively discussed in the Cumulative Effects section of the Draft EIS as a foreseeable future project(s). Once funding is identified for these extensions, a full environmental evaluation will be completed in a separate environmental study (or studies), as appropriate.

Figure 1-3 through Figure 1-6 (in Chapter 1, Background) show the proposed Build Alternatives and transit stations, including the areas designated as planned extensions.

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Acronyms and Abbreviations

ac	alternating current
ACGIH	American Conference of Governmental Industrial Hygienists
City	City and County of Honolulu
dc	direct current
EIS	environmental impact statement
ELF	extremely low frequency
EMC	electromagnetic compatibility
EMF	electromagnetic field
EMF-RAPID	EMF Research and Public Information Dissemination
EMI	electromagnetic interference
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
‘Ewa (direction)	toward the west (see also Wai‘anae)
ft	feet
FTA	Federal Transit Administration
G	gauss
GPS	Global Positioning System
H-1	Interstate Route H-1 (the H-1 Freeway)
HCN	Health Council of the Netherlands
HDOH	Hawai‘i State Department of Health
HECO	Hawaiian Electric Company
HRS	Hawai‘i Revised Statutes
Hz	hertz
IARC	International Agency for Research on Cancer
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
Koko Head (direction)	toward the east
kV/m	kilovolts per meter
makai (direction)	toward the sea
mauka (direction)	toward the mountains
mG	milligauss
MRI	magnetic resonance imaging
NEPA	National Environmental Policy Act

NIEHS	National Institute of Environmental Health Sciences
NRPB	National Radiological Protection Board of Great Britain
NTP	National Toxicology Program
O‘ahuMPO	O‘ahu Metropolitan Planning Organization
OSHA	Occupational Safety and Health Administration
RTD	City and County of Honolulu Department of Transportation Services Rapid Transit Division
T	tesla
TPSS	traction power substantion
UH	University of Hawai‘i
USC	U.S. Code
USDOE	U.S. Department of Energy
V/m	volts per meter
Wai‘anae (direction)	toward the west (see also ‘Ewa)
WHO	World Health Organization

Summary

Both electric and magnetic fields occur naturally in our environment. Examples of electric fields are those produced from strokes of lightning and static electricity. Examples of magnetic fields are permanent magnets and the earth's geomagnetic field.

Electromagnetic interference (EMI) derives from the presence of unwanted electromagnetic fields (EMF). EMF is produced by voltages and currents wherever wires distribute electric power and wherever electrical equipment is used. Unwanted magnetic fields can also occur whenever there is magnetized ferromagnetic material present, such as an automobile, bus, or train. These unwanted fields get combined with any existing field and cause a change to occur. Depending on the frequency and duration of these unwanted fields, these changes can interfere with the proper functioning of other nearby equipment. EMF levels decrease with distance away from operating equipment or away from current-carrying electric lines. EMF levels can also be decreased by a variety of mitigation methods discussed in Chapter 6, Mitigation.

The City and County of Honolulu Department of Transportation Services Rapid Transit Division (RTD), in coordination with the U.S. Department of Transportation Federal Transit Administration (FTA), is preparing a Draft EIS to evaluate alternatives that would provide high-capacity transit service on O‘ahu. The project study area is the travel corridor between Kapolei and University of Hawai‘i at Mānoa (UH Mānoa).

Field Survey

The EMF investigation included a field survey of the study corridor to determine whether any scientific, medical, military, or manufacturing facilities that may contain highly sensitive receptors are located within 200 feet of the proposed alignment. The results of the survey found 22 sites of the following types:

- Commercial—medical office (6 sites)
- Institutional—hospital/clinic (3 sites)
- Institutional—medical/diagnostic (1 site)
- Institutional—university/research (5 sites)
- Military—operations (1 site)
- Utility Station—electric (3 sites)
- Utility Station—telephone (3 sites)

In September 2008 the facility managers of these facilities were contacted through site visits and telephone calls to determine if the buildings contained any sensitive electronic equipment. All but one facility were eliminated; the Honolulu Community

College has an electron microscope that would be between 200 and 250 feet from the alignment.

Current State of the Science

The EMF investigation also included current state of the science research on the health effects of EMF and the level of effect, if any, that the Project would have on the community. Although research is ongoing both nationally and internationally, there is still no scientific evidence linking exposure to magnetic fields in the extremely low frequency range (the levels anticipated from the Project) to health issues.

A review was also performed to note the potential for existing EMF, such as power transmission lines along Dillingham Boulevard, to affect the Project.

Wherever electric propulsion is used, the key determinants of EMF and EMI potential are

- The magnitude of electric currents and voltages used by the vehicles
- The mass and size of the ferromagnetic material in the vehicle (for “moving metal” fields)
- The proximity of sensitive receptors to the transit corridor
- The pattern of current and voltage time variations
- The spatial configuration of the conductors supplying electric power
- The quantity of traffic
- The degree of EMF/EMI isolation required by sensitive receptors

It is expected that the magnetic component of EMF produced by the Project is likely to be the most problematic in terms of interference with sensitive research measurements. Depending on the rate and duration of the change and the instrument’s orientation relative to the right-of-way, it was found that some of these instruments can be sensitive to changes as small as 1 milligauss (mG). Table S-1 shows a very preliminary prediction of the magnetic field densities for light rail and rapid rail transit technologies versus distance from the Project’s centerline. These predictions are simplified and based on maximum current draw and assume the current to be coming from one substation when in reality the current will be split between adjacent substations. The information in Table S-1 illustrates that the Project could adversely affect highly sensitive instruments (sensitive to 1 mG) within 200 feet of its centerline.

Table S-1: Preliminary Magnetic Field Prediction for Light Rail and Rapid Rail Transit Technologies

Technology	Max Current	Distance Between Current Paths	Magnetic Field Density (mG) vs Distance (ft)			
			15	50	100	200
Light rail	3,600	4'-6¼"	475	43	11	3
Rapid rail	4,500	4'-6¼"	593	53	13	3

The EMF associated with light rail and rapid rail transit can be reduced by two main types of mitigation:

- Mitigation at the source
- Mitigation at the receptor location

Mitigation at the source requires incorporating mitigation features into the design prior to construction. The primary mitigation would be to ensure that the conductors carrying the electric current to and from the electric propulsion motors travel as close to each other as feasible, and to minimize sneak current paths (i.e., ensure that the supply and return currents are of equal magnitude). Mitigation using current path alignment has been used on other projects and can achieve a several-fold attenuation, depending on the details of current paths before and after alignment.

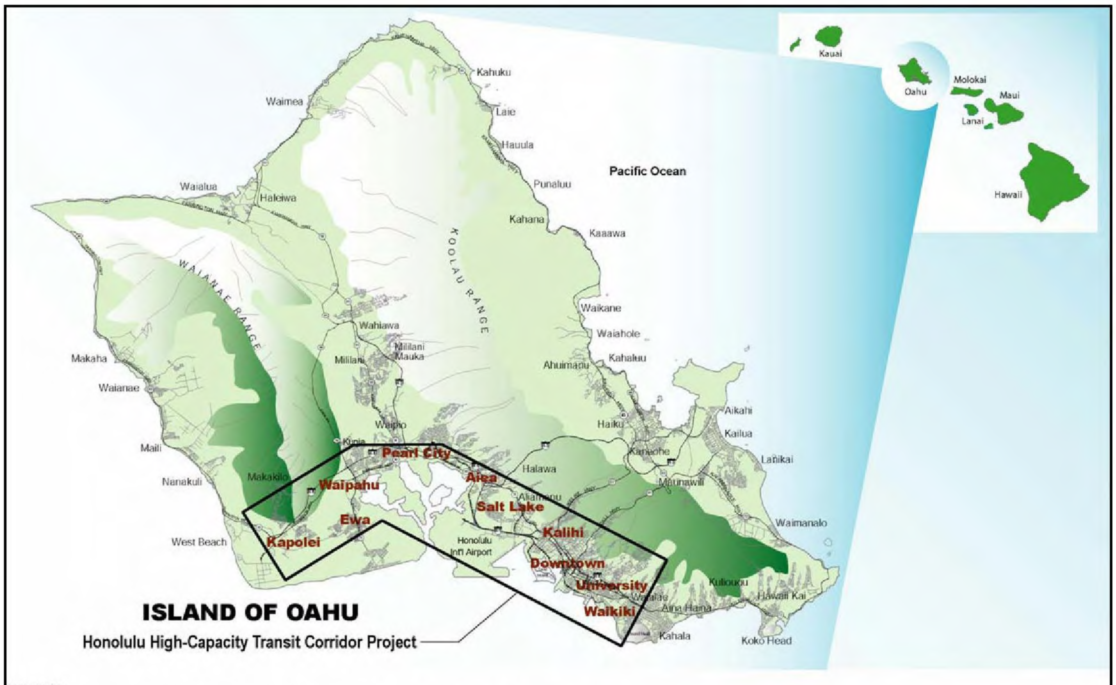
The primary candidate for mitigation at the receptor location is placing high-permeability ferromagnetic "mu-metal" sheets in locations that shunt the magnetic field lines away from sensitive areas. This approach can be laboratory-specific, can be undertaken after operation begins, and can be implemented on an as-needed basis. This magnetic shielding is a common approach already used by many laboratories that conduct sensitive measurements in electrically noisy environments. Depending on the number of shielding layers used, attenuation factors of 10 to 200 can be achieved. Another mitigation method involves electronic detection of the interfering field and generation of a canceling magnetic field that counteracts the EMF/EMI at the location that must be protected from interference. This active electronic method has been used successfully in situations where power line fields have caused problems, but it is expensive and maintenance-intensive.

If during preliminary engineering it is determined that the Honolulu Community College's electron microscope would be affected by the Project, mitigation measures would be evaluated to reduce EMF effects on the equipment.

1 Background

1.1 Introduction

The City and County of Honolulu Department of Transportation Services Rapid Transit Division (RTD), in cooperation with the U.S. Department of Transportation Federal Transit Administration (FTA), is evaluating fixed-guideway alternatives that would provide high-capacity transit service on O‘ahu. The project study area is the travel corridor between Kapolei and the University of Hawai‘i at Mānoa (UH Mānoa) (Figure 1-1). This corridor includes the majority of housing and employment on O‘ahu. The east-west length of the corridor is approximately 23 miles. The north-south width is, at most, 4 miles because the Ko‘olau and Wai‘anae Mountain Ranges bound much of the corridor to the north and the Pacific Ocean to the south.



SOURCES:
ESRI Atlas GIS v4.0 1998; Information Delivery System (IDS), March 1996; City and County of Honolulu, October 1998.

Figure 1-1: Project Vicinity

1.2 Description of the Study Corridor

The Honolulu High-Capacity Transit Corridor extends from Kapolei in the west (Wai‘anae or ‘Ewa direction) to UH Mānoa in the east (Koko Head direction) and is confined by the Wai‘anae and Ko‘olau Mountain Ranges in the mauka direction (towards the mountains, generally to the north within the study corridor) and the Pacific Ocean in the makai direction (towards the sea, generally to the south within the study corridor). Between Pearl City and ‘Aiea, the corridor’s width is less than 1 mile between Pearl Harbor and the base of the Ko‘olau Mountains (Figure 1-2).

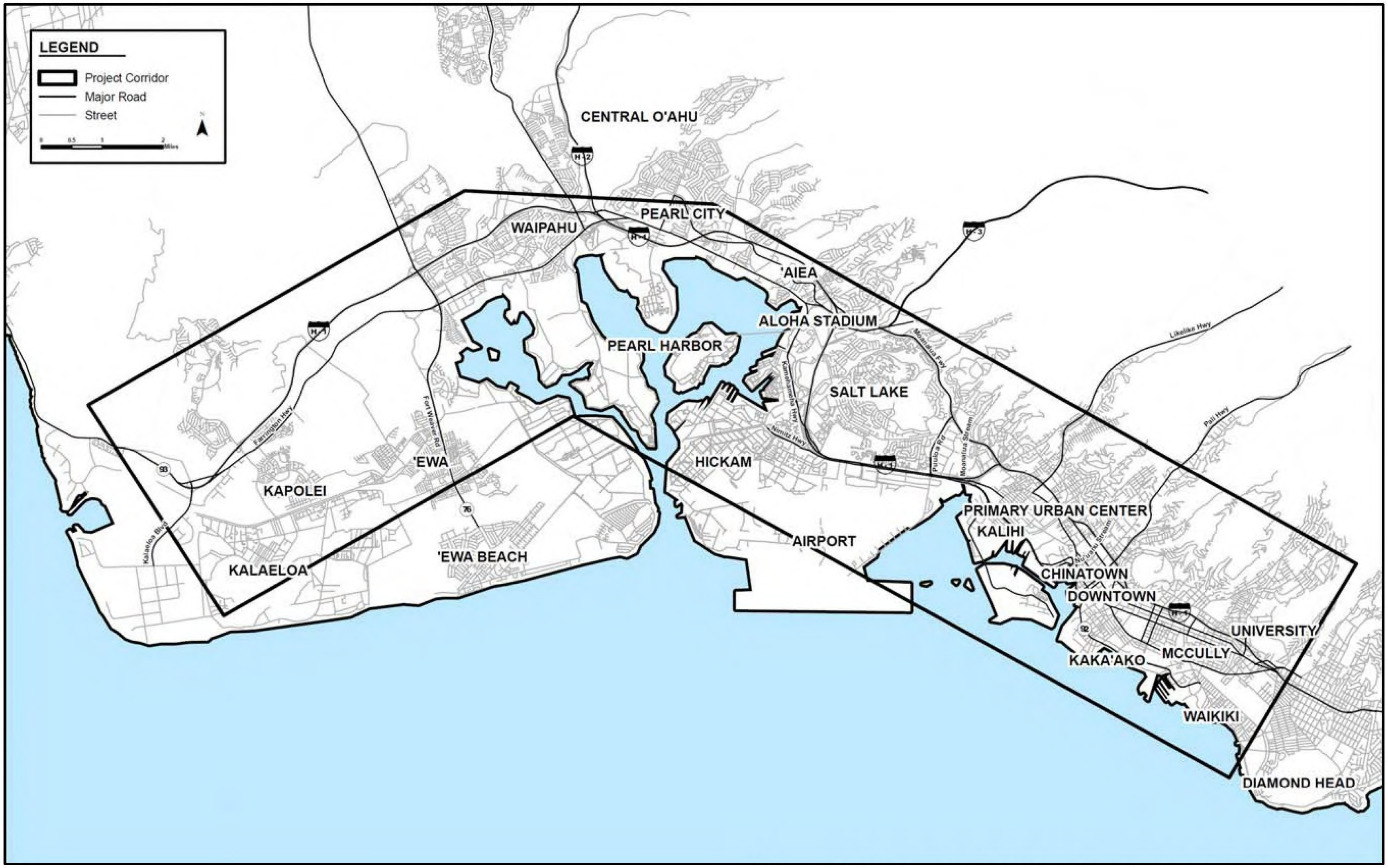


Figure 1-2: Areas and Districts in the Study Corridor

1.3 Alternatives

Four alternatives are being evaluated in the Environmental Impact Statement (EIS). They were developed through a screening process that considered alternatives identified through previous transit studies, a field review of the study corridor, an analysis of current and projected population and employment data for the corridor, a literature review of technology modes, work completed by the Oʻahu Metropolitan Planning Organization (OʻahuMPO) for its *Oʻahu Regional Transportation Plan 2030* (ORTP) (OʻahuMPO 2007), a rigorous Alternatives Analysis process, selection of a Locally Preferred Alternative by the City Council, and public and agency comments received during the separate formal project scoping processes held to satisfy National Environmental Policy Act (NEPA) (USC 1969) requirements and the Hawaiʻi EIS Law (Chapter 343) (HRS 2008). The alternatives evaluated are as follows:

1. No Build Alternative
2. Salt Lake Alternative
3. Airport Alternative
4. Airport & Salt Lake Alternative

1.3.1 No Build Alternative

The No Build Alternative includes existing transit and highway facilities and committed transportation projects anticipated to be operational by 2030. Committed transportation projects are those identified in the ORTP, as amended (OʻahuMPO 2007). Highway elements of the No Build Alternative also are included in the Build Alternatives. The No Build Alternative would include an increase in bus fleet size to accommodate growth, allowing service frequencies to remain the same as today.

1.3.2 Build Alternatives

The fixed guideway alternatives would include the construction and operation of a grade-separated fixed guideway transit system between East Kapolei and Ala Moana Center (Figure 1-3 to Figure 1-6). Planned extensions are anticipated to West Kapolei, UH Mānoa, and Waikīkī. The system evaluated a range of fixed-guideway transit technologies that met performance requirements, which could be either automated or employ drivers. All parts of the system would either be elevated or in exclusive right-of-way.

Steel-wheel-on-steel-rail transit technology has been proposed through a comparative process based on the ability of various transit technologies to cost-effectively meet project requirements. As such, this technology is assumed in this analysis.

The guideway would follow the same alignment for all Build Alternatives through most of the study corridor. The Project would begin by following North-South Road and other future roadways to Farrington Highway. Proposed station locations and other project features in this area are shown in Figure 1-3. The guideway would follow Farrington Highway Koko Head on an elevated structure and continue along Kamehameha Highway to the vicinity of Aloha Stadium (Figure 1-4).

Between Aloha Stadium and Kalihi, the alignment differs for each of the Build Alternatives, as detailed later in this section (Figure 1-5). Koko Head of Middle Street, the guideway would follow Dillingham Boulevard to the vicinity of Kaʻaahi Street and then turn Koko Head to connect to Nimitz Highway in the vicinity of Iwilei Road.

The alignment would follow Nimitz Highway Koko Head to Halekauwila Street, then along Halekauwila Street past Ward Avenue, where it would transition to Queen Street and Kona Street. Property on the mauka side of Waimanu Street would be acquired to allow the alignment to cross over to Kona Street. The guideway would run above Kona Street through Ala Moana Center.

Planned extensions would connect at both ends of the corridor. At the Waiʻanae end of the corridor, the alignment would follow Kapolei Parkway to Wākea Street and then turn makai to Saratoga Avenue. The guideway would continue on future extensions of Saratoga Avenue and North-South Road. At the Koko Head end of the corridor, the alignment would veer mauka from Ala Moana Center to follow Kapiʻolani Boulevard to University Avenue, where it would again turn mauka to follow University Avenue over the H-1 Freeway to a proposed terminal facility in UH Mānoa's Lower Campus. A branch line with a transfer point at Ala Moana Center or the Hawaiʻi Convention Center into Waikīkī would follow Kalākaua Avenue to Kūhiō Avenue to end near Kapahulu Avenue (Figure 1-6).

Salt Lake Alternative

The Salt Lake Alternative would leave Kamehameha Highway immediately ʻEwa of Aloha Stadium, cross the Aloha Stadium parking lot, and continue Koko Head along Salt Lake Boulevard (Figure 1-5). It would follow Pūkōloa Street through Māpunapuna before crossing Moanalua Stream, turning makai, crossing the H-1 Freeway and continuing to the Middle Street Transit Center. Stations would be constructed near Aloha Stadium and Ala Likoʻi. The total guideway length for this alternative would be approximately 19 miles and it would include 19 stations. The eventual guideway length, including planned extensions, for this alternative would be approximately 28 miles and it would include 31 stations.

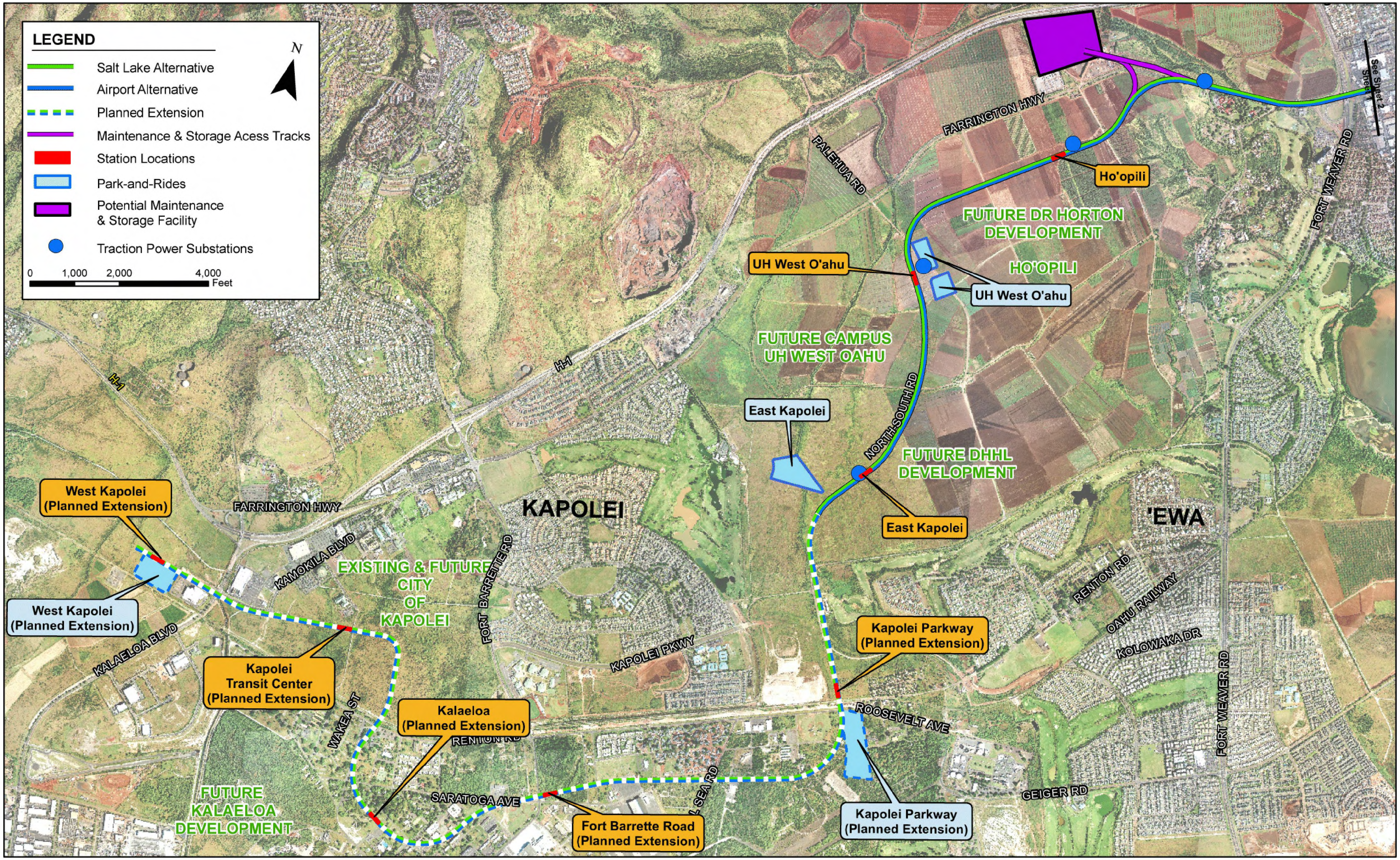


Figure 1-3: Fixed Guideway Transit Alternative Features (Kapolei to Fort Weaver Road)

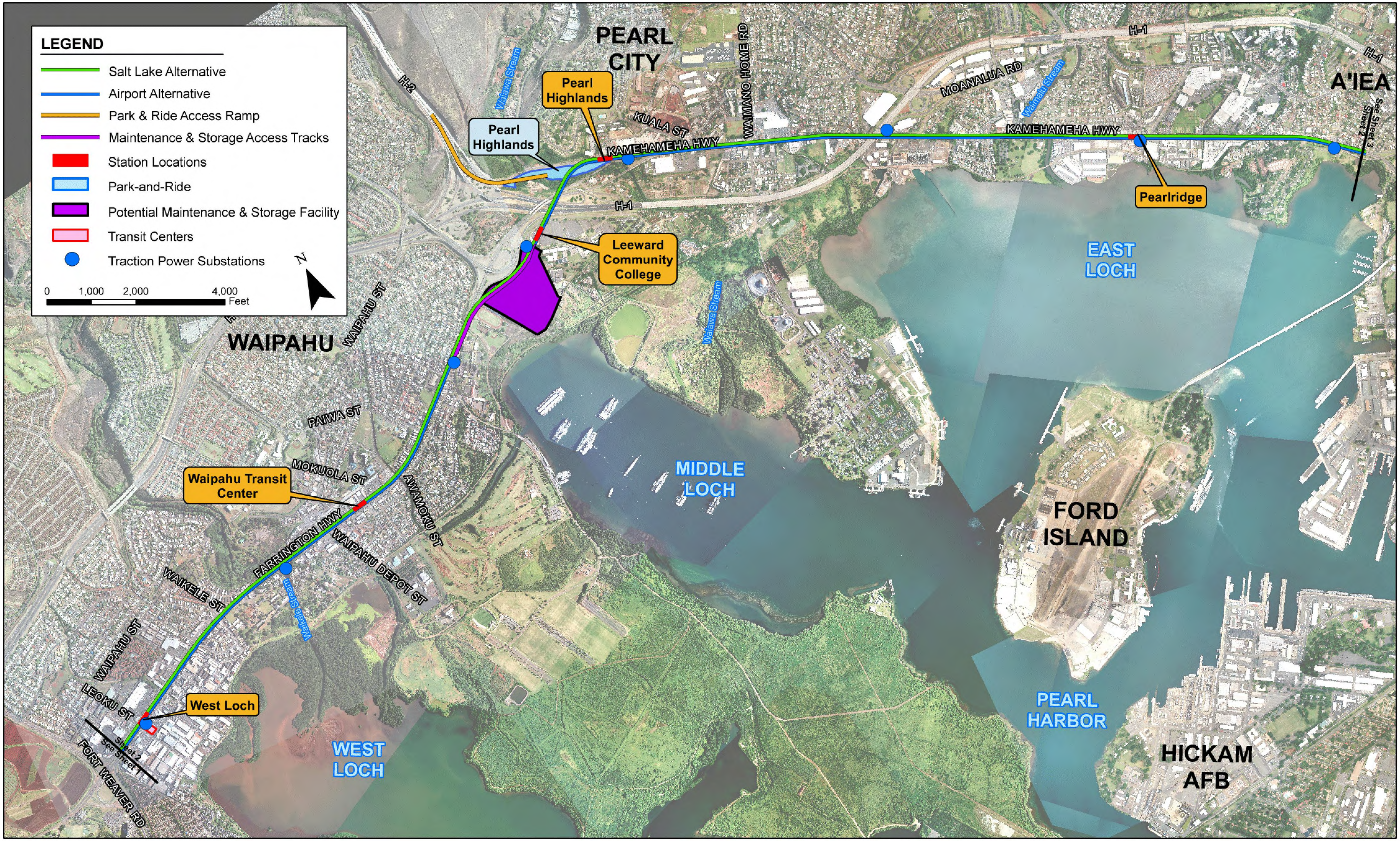


Figure 1-4: Fixed Guideway Transit Alternative Features (Fort Weaver Road to Aloha Stadium)

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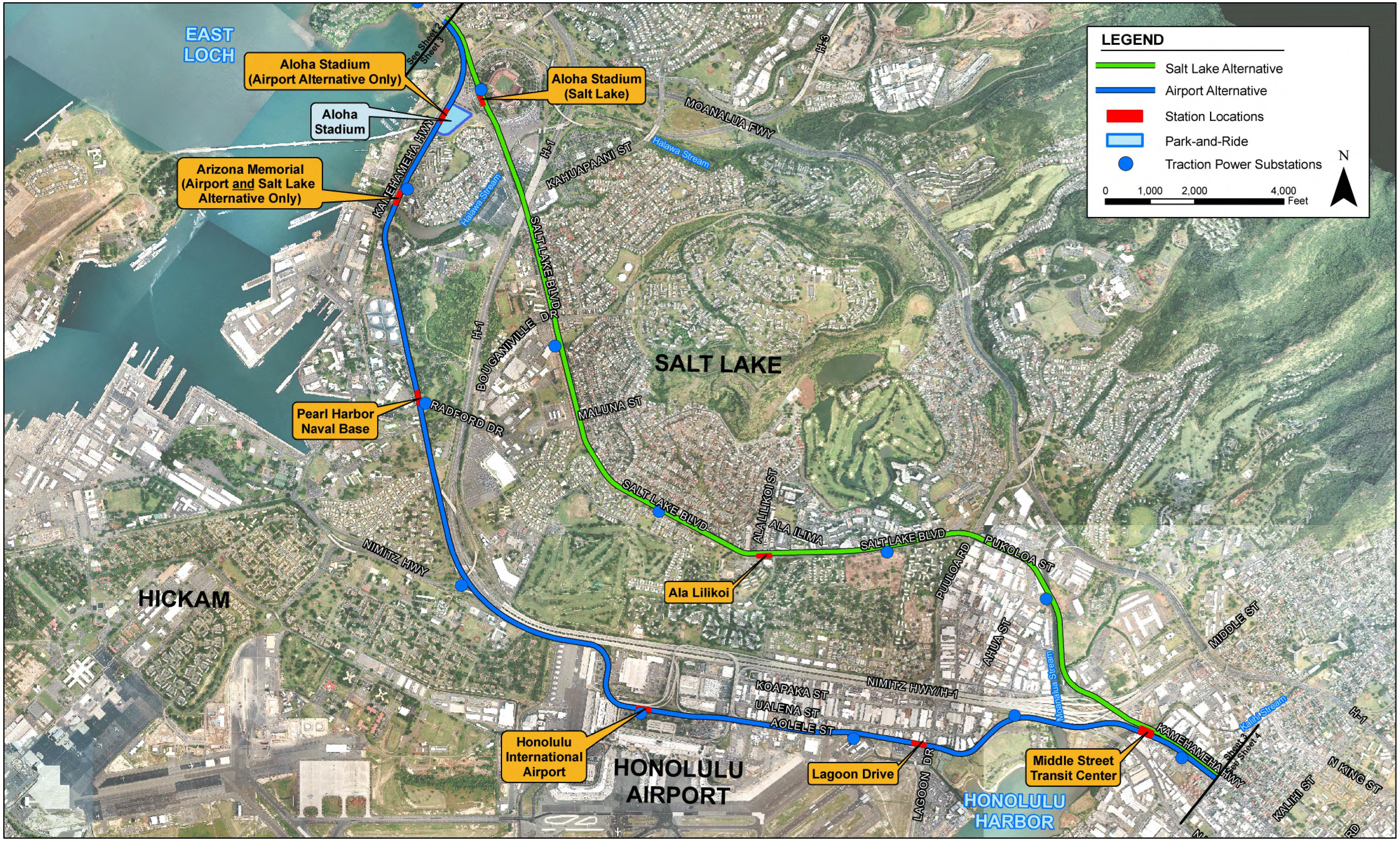


Figure 1-5: Fixed Guideway Transit Alternative Features (Aloha Stadium to Kalihi)

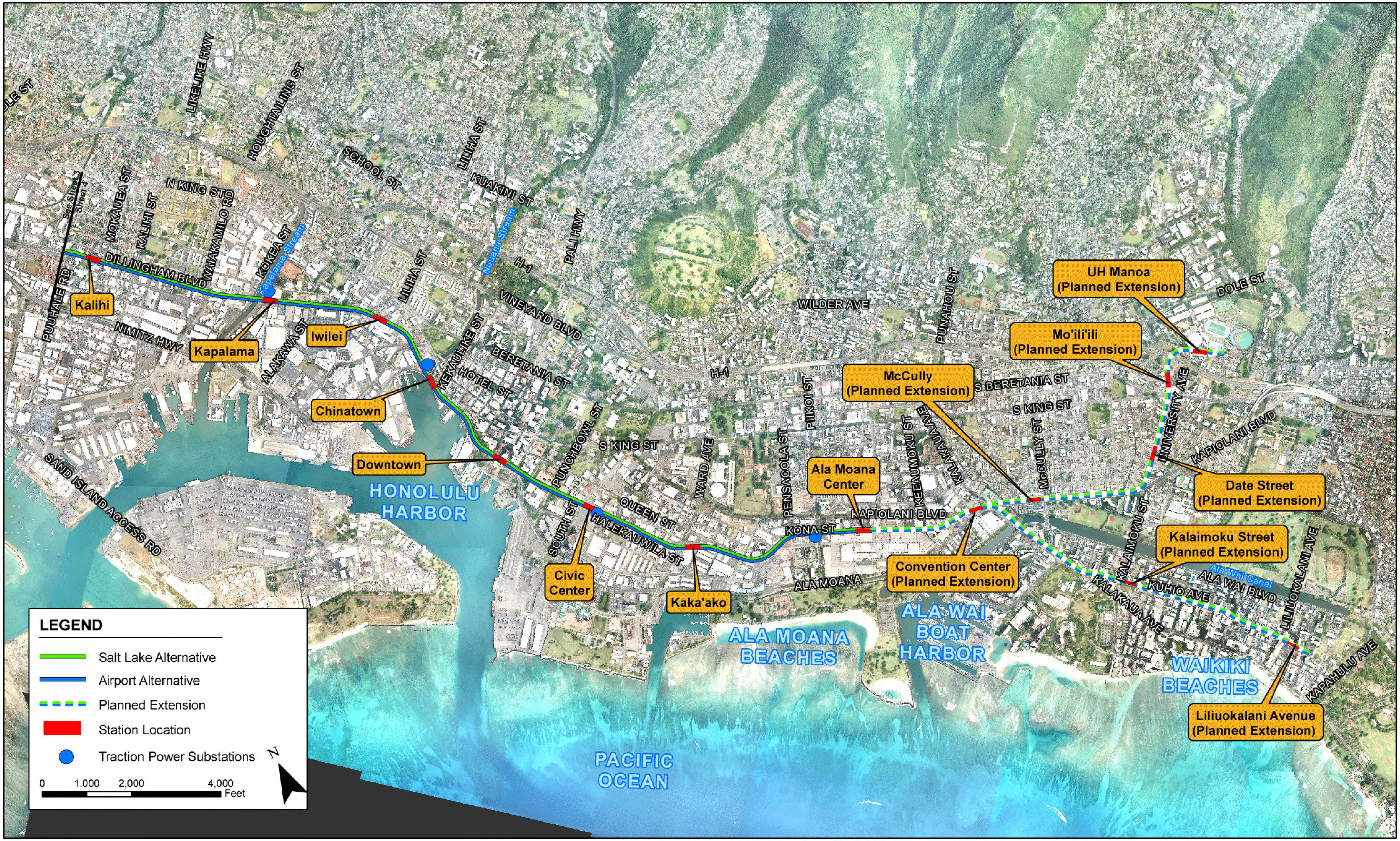


Figure 1-6: Fixed Guideway Transit Alternative Features (Kalihi to UH Mānoa)

Airport Alternative

The Airport Alternative would continue along Kamehameha Highway makai past Aloha Stadium to Nimitz Highway and turn makai onto Aolele Street and then follow Aolele Street Koko Head to reconnect to Nimitz Highway near Moanalua Stream and continuing to the Middle Street Transit Center (Figure 1-5). Stations would be constructed at Aloha Stadium, Pearl Harbor Naval Base, Honolulu International Airport, and Lagoon Drive. The total guideway length for this alternative would be approximately 20 miles and it would include 21 stations. The eventual guideway length, including planned extensions, for this alternative would be approximately 29 miles and it would include 33 stations.

Airport & Salt Lake Alternative

The Airport & Salt Lake Alternative is identical to the Salt Lake Alternative, with the exception of also including a future fork in the alignment following Kamehameha Highway and Aolele Street at Aloha Stadium that rejoins at Middle Street. The station locations discussed for the Salt Lake Alternative would all be provided as part of this alternative. Similarly, all the stations discussed for the Airport Alternative also would be constructed at a later phase of the project; however, the Aloha Stadium Station would be relocated makai to provide an Arizona Memorial Station instead of a second Aloha Stadium Station. At the Middle Street Transit Center Station, each line would have a separate platform with a mezzanine providing a pedestrian connection between them to allow passengers to transfer. The total guideway length for this alternative would be approximately 24 miles and it would include 23 stations. The eventual guideway length, including planned extensions, for this alternative would be approximately 34 miles and it would include 35 stations.

1.3.3 Features Common to All Build Alternatives

In addition to the guideway, the project will require the construction of stations and supporting facilities. Supporting facilities include a maintenance and storage facility, transit centers, park-and-ride lots, and traction power substations (TPSS). The maintenance and storage facility would either be located between North-South Road and Fort Weaver Road or near Leeward Community College (Figure 1-3 and Figure 1-4). Some bus service would be reconfigured to transport riders on local buses to nearby fixed guideway transit stations. To support this system, the bus fleet would be expanded.

2 Studies and Coordination

2.1 Overview of Electric and Magnetic Fields

2.1.1 Electric Fields

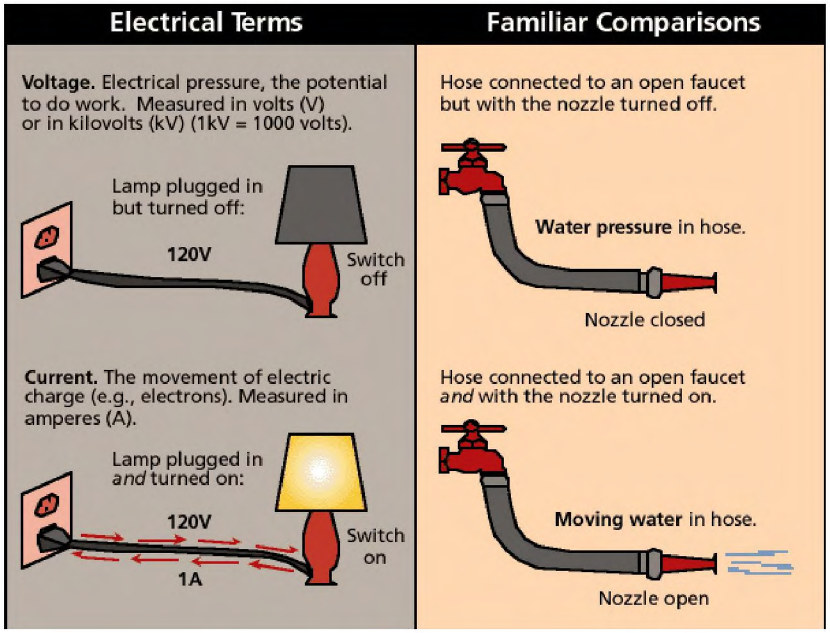
Electric fields are a result of the voltage or electric potential on an object. Any object with an electric charge on it has a voltage at its surface, which is caused by the accumulation of more electrons on that surface compared to another object or surface (Figure 2-1).

The voltage effect is not limited to the object's surface, but exists in the space surrounding it. The change in voltage over distance is known as the *electric field*. The units describing an electric field are volts per meter (V/m) or kilovolts per meter (kV/m). The electric field is strongest near a charged object and decreases rapidly with increasing distance from an object. Electric fields are a common phenomenon. Static electric fields can result from taking off a sweater or walking across a carpet. Most household appliances and other devices that operate on electricity create electric fields. An appliance doesn't need to be in operation to create an electric field; this field exists whenever it is plugged into an outlet. Electric fields are shielded by objects in the environment, especially objects that conduct electricity. For example, buildings, tall fences, and even trees can partially shield electric fields originating from nearby power lines.

2.1.2 Magnetic Fields

Whenever an electrical current flows through a conductor (e.g., a power line, electrical equipment, or a household appliance) it creates a magnetic field, and the strength of the field increases as the current increases. Unlike the electric field, the magnetic field does not have a beginning or an end, but forms closed, continuous loops of force around the source of the field. Also unlike electric fields, magnetic fields are only present when an electrical device is in operation or a wire is transmitting electricity, because they are caused by the flow of current through a wire.

Like electric fields, the strength of magnetic fields decreases with distance (Figure 2-2). Magnetic fields are measured in units of gauss (G) or tesla (T). Most electrical equipment has to be turned on (i.e., current must be flowing) for a magnetic field to be produced. In contrast to electric fields, magnetic fields can pass through most objects and can be blocked only by special shielding materials.



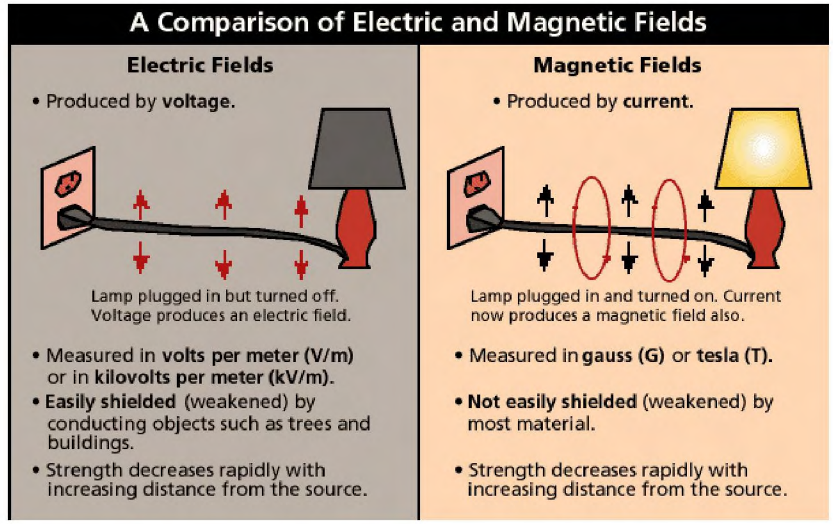


Figure 2-1: Electrical Terms and Comparisons

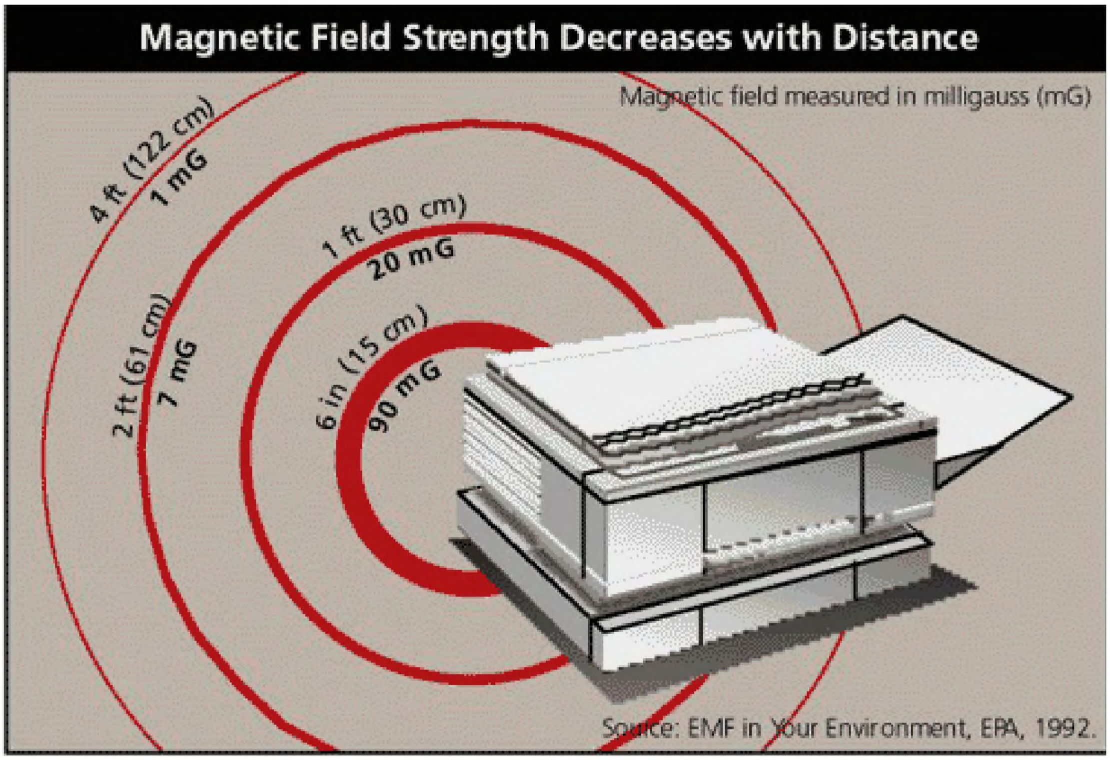


Figure 2-2: Magnetic Field Strength

Even though electrical equipment, appliances, and power lines produce both electric and magnetic fields, most recent research has focused on potential health effects of magnetic field exposure. This is because some epidemiological studies have reported an increased cancer risk associated with magnetic field exposure. No similar associations have been reported for electric fields; many studies examining the biological effects of electric fields were essentially negative and are summarized below.

2.2 Electric and Magnetic Field Standards, Guidelines, and Policies

2.2.1 Federal Transit Administration

By the mid-1970s, the use of solid-state traction motor controllers on several transit systems had been introduced. On one property, it was discovered that electromagnetic interference from the controllers was interfering with the safe operation of the signal system. As a result, the Urban Mass Transportation Administration, now known as the FTA, initiated the Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) program. A technical working group was created to thoroughly investigate rail transit EMI and provide procedures for assuring the electromagnetic compatibility of transit electric equipment. In 1987, a final report was published with a series of recommendations and suggested test procedures dealing with conductive, inductive, and radiated emissions. These test procedures included limits for each type of emission, which are still commonly included in transit vehicle procurement specifications.

An Internet research of the FTA website did not reveal any EMF standards, guidelines, and policies in connection with power distribution systems.

2.2.2 U.S. Environmental Protection Agency

The Environmental Protection Agency (EPA) issued a booklet *Questions and Answers about Electric and Magnetic Fields (EMF)* (402-R-92-009) in December 1992. This document stated that neither the EPA nor any other Federal regulatory agency has established a standard for EMF, because scientific evidence is inadequate to determine whether magnetic fields are harmful and, if they are harmful, at what levels.

2.2.3 U.S. Department of Labor Occupational Safety & Health Administration

According to the U.S. Department of Labor Occupational Safety & Health Administration (OSHA) website, there are currently no specific OSHA standards that address extremely low frequency (ELF) fields. However, there are national consensus standards and standards from the United Kingdom that OSHA could consider referencing in a general duty clause citation in cases where inspections of an employer's workplace finds exposure levels exceeding those standards.

National Consensus

Institute of Electrical and Electronic Engineers

The Institute of Electrical and Electronic Engineers (IEEE)'s *Standard C95.6-2002, Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz* (IEEE 2002), defines exposure levels to protect against adverse effects in humans from exposure to electric and magnetic fields at frequencies from 0 to 3 kHz.

Electric Power Research Institute

The Electric Power Research Institute (EPRI)'s *Comments on the IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0 to 3 kHz* (EPRI 2002), states that the IEEE standard represents a clear advancement in the development and documentation of exposure guidelines in the designated frequency range.

American Conference of Governmental Industrial Hygienists

The American Conference of Governmental Industrial Hygienists (ACGIH) publishes "Threshold Limit Values" for various physical agents. The Threshold Limit Values it suggests for 60-Hz EMF are shown in Table 2-1. They are identified as guides to control exposure; they are not intended to demarcate safe and dangerous levels.

Table 2-1: ACGIH Guidelines for Occupational Exposure to 60-Hz EMF

Exposure Guideline	Electric Field	Magnetic Field
Occupational exposure should not exceed	25 kV/m	10,000 mG
Prudence dictates the use of protective clothing above	15 kV/m	—
Exposure of workers with cardiac pacemakers should not exceed	1 kV/m	1,000 mG

ACGIH is a professional organization that facilitates the exchange of technical information about worker health protection. It is not a government regulatory agency.
mG = magnetic field density
Source: ACGIH 2001.

International Commission on Non-Ionizing Radiation Protection Guidelines

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) of the International Radiation Protection Association has published guidelines for EMF exposure (ICNIRP 1998) (Table 2-2). The organization confirmed these guidelines after considering evidence in laboratory and epidemiological studies of both occupational and general populations. Its conclusion is that the data related to cancer does not provide a basis for assessing the health risks of human exposure to power frequency fields.

Table 2-2: Guidelines on Limits of Exposure to 50-60 Hz EMF

Exposure Characteristics	Electric Field	Magnetic Field
General public exposure	4.16 kV/m	830 mG
Occupational exposure	8.3 kV/m	4,160 mG

Note: ICNIRP is an organization of 15,000 scientists from 40 nations who specialize in radiation protection.
mG – magnetic field density
Source: ICNIRP 1998.

2.2.4 State of Hawai'i Department of Health

On January 19, 1994, the Hawai'i State Department of Health (HDOH) issued a statement titled *HDOH Policy Relating to Electric and Magnetic Fields from Power-Frequency Sources* (HDOH 1994). The statement reads as follows:

> "The Department of Health, in response to continuing but inconclusive scientific investigation concerning EMF from low-frequency power sources, recommends a "prudent avoidance" policy. "Prudent avoidance" means that reasonable, practical, simple, and relatively inexpensive actions should be considered to reduce exposure.
>
> A cautious approach is suggested at this time concerning exposure to EMF around low frequency sources, such as electric appliances and power lines. The existing research data on possible adverse health effects, including cancer, are inconclusive and not adequate to establish or quantify a health risk. For example, the biological mechanisms that might underlie any apparent relationship between EMF and cancer have yet to be clearly defined. Also, some epidemiological studies suggest that, if these fields

> increase the risk of cancer, it is a very small increase. Other epidemiological studies suggest that there is no increased risk.
>
> The Department of Health will continue to collect and evaluate information on possible health hazards associated with electric and magnetic fields. If adequate data ever become available to establish what levels may be harmful, appropriate standards will be established."

2.2.5 State of Hawai'i Public Utilities Commission

The Public Utilities Commission, in reaching its decision on the Waiau-CIP Transmission Lines Project, considered potential adverse health effects from the project's magnetic fields. The Public Utilities Commission considered extensive testimony by national experts with different viewpoints, submitted during the evidentiary hearing and related proceedings. The Public Utilities Commission's position on this issue is contained in its Decision and Order, which states as follows:

> "Based upon a thorough examination of all of the evidence presented in this docket with regard to the possible health effects of exposure to EMF, we find that a causal link between EMF and adverse health effects has yet to be established by those in the scientific community who have been researching this matter. We will, however, expect HECO [Hawaiian Electric Company] to exercise "prudent avoidance" with respect to EMF."

The Public Utilities Commission's position in the Decision and Order adopted the following explanation of prudent avoidance put forth by the EPA in its *Questions and Answers about Electric and Magnetic Fields (EMF)*:

> "Prudent avoidance is an approach to making decisions about risks. This decision-making process is based on judgment and values, can be applied to groups and individuals, and can be considered for all aspects of our lives, not just EMFs. Prudent avoidance applied to EMFs suggests adopting measures to avoid EMF exposures when it is reasonable, practical, relatively inexpensive and simple to do. This position or course of action can be taken even if the risks are uncertain and even if safety issues are unresolved."

2.2.6 World Health Organization

The World Health Organization (WHO) recently completed its review of the state of research on the health issues associated with exposure to ELF electromagnetic fields. The conclusions and recommendations are presented in a WHO Environmental Health Criteria monograph (WHO 2007b). The results of this review found that for high-level (well above 1,000 mG) short-term exposures, there are recognized biophysical mechanisms, such as induced currents, causing nerve and muscle stimulation and nerve cell excitability. In response, WHO issued guidelines that are presented in more detail in Chapter 5 of this report.

2.3 Health Effects of Electric and Magnetic Fields

2.3.1 Overview

Public concern regarding possible health risks from residential and occupational exposure to low-strength, low-frequency EMF produced by power lines and electrical appliances has generated considerable debate among scientists and public officials. The concern over power frequency magnetic fields began with an epidemiological study of childhood leukemia conducted by Wertheimer and Leeper (Wertheimer 1979) in Denver, Colorado in 1979. Until this study, no association between magnetic fields and human health had been reported. Since then, some epidemiology studies have reported similar associations while others have not.

Epidemiology is the study of patterns of health and disease in human populations. Interpretation of epidemiological studies regarding potential causal relations between exposures and health outcomes is a complex process and relies upon a wide range of supporting data. Although some studies have reported positive associations between magnetic fields and human health effects, the number of well-designed studies supporting this association is not sufficient to conclude that the association is causal.

Mechanistic and animal toxicology studies have failed to demonstrate any consistent pattern of biological effects, such as increased cancers in animals. This lack of connection between human data (epidemiology) and experimental data (mechanistic and animal) weakens the belief that observed health effects are caused by EMF.

In 1992, Congress mandated an EMF research program, which was managed by the National Institute of Environmental Health Sciences (NIEHS). In 1998, the NIEHS convened a working group to evaluate the results of this research program and other EMF research. The working group concluded that the epidemiologic data were limited, but categorized EMF as possibly carcinogenic.

At the same time, using the methods routinely applied by the National Toxicology Program (NTP) of the National Institute of Health, the NIEHS concluded that EMF exposure would not be listed in the *NTP Report on Carcinogens* as a "known human carcinogen" or as "reasonably anticipated to be a human carcinogen." The NIEHS reported to the U.S. Congress that the probability that EMF is a health hazard is relatively small and evidence is insufficient to warrant aggressive regulatory actions (NIEHS 1999). It recommended the following:

> "…the power industry continue its current practice of siting power lines to reduce exposures and continue to explore ways to reduce the creation of magnetic fields around transmission and distribution lines without creating new hazards" (p. 38).

The NIEHS further stated:

> "The NIEHS believes that the probability that ELF-EMF [Extremely-Low-Frequency EMF] exposure is truly a health hazard is currently small. The

> weak epidemiological associations and lack of any laboratory support for these associations provide only marginal, scientific support that exposure to this agent is causing any degree of harm.... The NIEHS concludes that ELF-EMF exposure cannot be recognized as entirely safe because of weak scientific evidence that exposure may pose a leukemia hazard" (NIEHS 1999 [p.36]).

In 1999, the National Academy of Sciences National Research Center, after reviewing and evaluating the research conducted under the U.S. Department of Energy (USDOE)/NIEHS National EMF Research and Public Information Dissemination (EMF-RAPID) Program, stated the following:

> "The results of the EMF-RAPID program do not support the contention that the use of electricity poses a major unrecognized public-health danger.... In view of the negative outcomes of the EMF-RAPID replication studies, it now appears even less likely that MFs [Magnetic Fields] in the normal domestic or occupational environment produce important health effects, including cancer" (NRC 1999 [pp. 78 and 8]).

2.3.2 Subsequent Evaluations of EMF Research

The epidemiological and laboratory data published in the United States after the NIEHS report was completed in 1998 have provided additional evidence that EMF does not contribute to childhood cancer. For example:

- Investigators at the National Cancer Institute reported no association between childhood leukemia and EMF in their study (Linet 1997), and a reanalysis using a different measure of exposure also found no evidence of cancer risk (Kleinerman 2000). In addition, the majority of studies of breast cancer have not supported an association with residential EMF (Gammon 1998; Forssén 2000; Kabat 2003; London 2003; Schoenfeld 2003).
- Laboratory studies published after the NIEHS report, some of which were part of the research program and available for review by the NIEHS, provide evidence for a lack of carcinogenicity or provide no basis to conclude that EMF affects the development or promotion of cancer (e.g., Anderson 1999; Boorman 1999; McCormick 1999; Morris 1999; Mandeville 2000).

Several organizations outside the United States have sponsored comprehensive reviews of EMF research by multidisciplinary groups of scientists. The International Agency for Research on Cancer (IARC), the ICNIRP, the Health Council of the Netherlands (HCN), and the National Radiological Protection Board of Great Britain (NRPB) have all convened large groups of independent scientists with different expertise (e.g., epidemiologists, toxicologists, biologists, neurobiologists, and physicists) to review the literature regarding EMF and health. Each organization has produced a report that is available to the public.

- A large (more than 1,000 cases) and well-designed epidemiologic study of childhood leukemia was conducted in England by the United Kingdom

Childhood Cancer Study investigators (UKCCS 1999). These researchers reported no increased risk of leukemia in those children with average annual exposures to EMF from 2 mG up to 4 mG in the home and school. No statistically significant increase was found for children whose exposure was above 4 mG—that is, a small increase was reported but chance could not be excluded as an explanation.

- IARC reviewers evaluated available animal data and concluded that they were “inadequate” to support a risk for cancer. The scientists stated that the EMF data do not merit the category “carcinogenic to humans” or the category “probably carcinogenic to humans,” nor did they find that “the agent is probably not carcinogenic to humans.” Many hypotheses have been suggested to explain possible carcinogenic effects of EMF, but no scientific explanation for carcinogenicity of these fields has been established (IARC 2002). In the rating system used by IARC, recognition of an association between exposure and cancer in epidemiology studies is considered “limited evidence” of carcinogenicity. A rating of “limited evidence” for epidemiology studies, even without any evidence from laboratory studies that an exposure might pose a cancer risk, requires that the exposure be categorized as a “possible carcinogen,” even though chance, bias, and confounding cannot be ruled out with reasonable confidence (IARC 2002).
- The IARC working group did not regard the association between magnetic fields and childhood leukemia as reflecting a causal association, because there was insufficient evidence from epidemiology studies that magnetic fields caused cancer in humans, insufficient evidence that magnetic fields caused cancer in laboratory studies of animals, and no evidence for a mechanism to lead to cancer. The working group concluded that the epidemiologic studies do not provide support for an association between childhood leukemia and residential magnetic fields at intensities less than 4 mG. Overall, magnetic fields were evaluated as “possibly carcinogenic to humans” (Group 2B), based on the statistical association of higher-level residential magnetic fields with childhood leukemia. Other very common materials have been classified as 2B as well, including coffee, pickled vegetables, and gasoline engine exhaust.
- The HCN’s reviews of scientific research regarding EMF and health were published in 2000 and updated in 2001 and 2004. ICNIRP published its review in 2003. The NRPB published reviews in 2001 and 2004, which included comprehensive discussions of individual research studies. Assessments by the NIEHS, IARC, ICNIRP, NRPB, and HCN agree that there is little evidence that EMF is associated with adverse health effects, including most forms of adult and childhood cancer, heart disease, Alzheimer’s disease, depression, and reproductive effects. However, all of the assessments concluded that the epidemiology studies in total suggest a possible association between magnetic fields at higher exposure levels (annual average greater than 4 mG) and childhood leukemia. All agree that the experimental laboratory data do not support a causal link between EMF

and any adverse health effect, including leukemia, and have not concluded that EMF is in fact the cause of any disease. These organizations have not recommended exposure limits or required measures to reduce exposures, since they have not concluded that a causal relationship exists between EMF and adverse health effects.

EMI derives from the presence of unwanted EMF. EMF is produced by voltages and currents wherever wires distribute electric power and wherever electrical equipment is used. EMF levels decrease with distance away from the operating equipment or away from current-carrying electric lines. EMF levels can also be decreased by a variety of mitigation methods, which are discussed in Chapter 6.

EMF is typically characterized by the type of field (electrical or magnetic), the intensity of the fields, and the time variation (frequency) of the fields which is given in hertz (Hz) (1 Hz equals one cycle per second). Natural sources of electric fields include the static electricity caused by materials rubbing against each other and the atmospheric electric fields that result in strokes of lightning. Natural sources of static magnetic fields include permanent magnets and the Earth's geomagnetic field. These natural EMF sources do not have the "60-times-per-second" (60-Hz) time variation that characterizes most electric power line magnetic fields.

3.1 Field Survey of Potentially Affected Facilities

Sensitive land uses that may be affected by changes to the Earth's geomagnetic field from operation of the Project could include research, manufacturing, medical, and possibly military facilities that use tools that depend on the stability of the Earth's field. These tools can include, but may not be limited to, electron microscopes, nuclear magnetic resonance spectrometers, and magnetic resonance imaging (MRI) equipment used for medical diagnostic purposes.

Verification of land uses in the study area was necessary, because the City and County of Honolulu (City) does not have a designated land use map in its General Plan. Therefore, the following steps were taken to establish existing conditions:

1. Prior to conducting field verification, the following land uses were mapped according to readily available data: high-voltage power lines, medical and diagnostic facilities, institutional and research facilities, and military operations.
2. Field reconnaissance using global positioning system (GPS) and photo-imaging equipment was conducted between December 3 and 13, 2007, to verify site locations and identify land uses that may be sensitive to the influence of EMF associated with the Project. Field verification of adjacent properties was conducted from public access areas and from within the project site, then categorized as follows:
   - Commercial—medical office
   - Institutional—hospital/clinic
   - Institutional—medical/diagnostic
   - Institutional—university/research

- Military—operations
- Utility—electrical towers
- Utility Station—electric

3. The gathered GPS data were georeferenced with the proposed alignment of the Project using ESRI's ArcGIS Explorer. A 400-foot-wide corridor from the alignment centerline was created and used to identify facilities located within 200 feet that may contain potentially affected tools.
4. In September 2008 the facility managers of these facilities were contacted through site visits and telephone calls to determine if the buildings contained any sensitive electronic equipment.

3.2 EMF Predictions

The steel wheel on steel rail vehicle technology chosen for the Project would require an electrification system to supply power for the traction and auxiliary power systems. The Project's rail technology would use a wayside contact line (third rail) as opposed to an overhead line for the supply, and running rails would be used for the return (Figure 3-1 and Figure 3-2). Sources of EMFs would include stations, transit vehicles, and transit power substations.

3.3 Health Effects of EMF—Current State of the Science

Since the late 1970s, questions have been raised about whether exposure to extremely low frequency EMF produces adverse health consequences. Since then, much research has been conducted, resolving important issues and narrowing the focus of future work. To determine the state of the science, extensive research was performed to identify the key organizations involved and review each organization's work that has been documented in published articles.

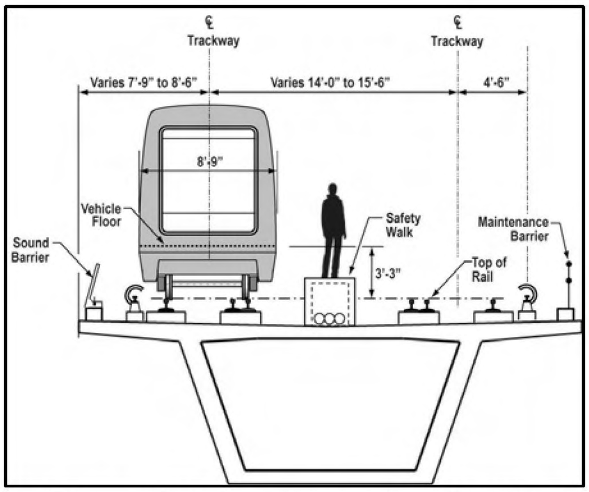


Figure 3-1: Example of LRT Vehicle on Elevated Guideway (Cross-Section)

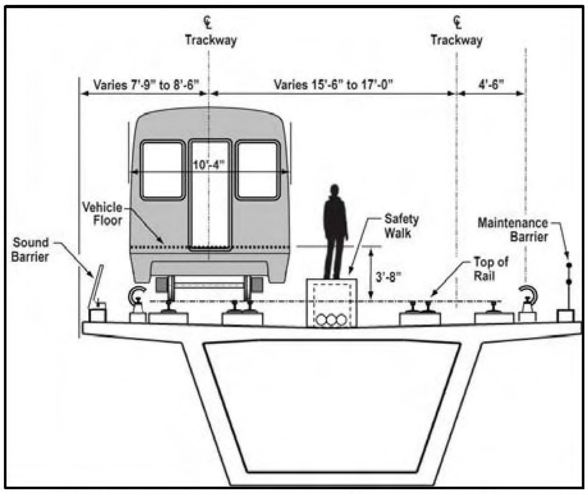


Figure 3-2: Example of Rail Rapid Transit Vehicle on Elevated Guideway (Cross-Section)

4 Affected Environment

Table 4-1 is a list of locations found during the field survey that are within 200 feet of the proposed alignment centerline. These locations may have sensitive electronic equipment that could be affected by operation of the Project. In September 2008 the facility managers of these facilities were contacted through site visits and telephone calls to determine if the buildings contained any sensitive electronic equipment. All but one facility were eliminated; the Honolulu Community College has an electron microscope that would be between 200 and 250 feet from the alignment.

Table 4-1: Location of Potential EMF Receptors within 200 Feet of the Alignment

Address	Building Name
Commercial—Medical Office	
94307 Farrington Highway	Waipahu Medical Center
94869 Farrington Highway	First Physical and Functional Rehab
94873 Farrington Highway	Vision Care Centers of Hawai‘i
1728 Dillingham Boulevard	Dillingham Medical Building
1748 Dillingham Boulevard	Dillingham Medical Building
1960 Kaipii Street*	McCully Shopping Center
Institutional—Hospital/Clinic	
912127 Fort Weaver Road	Maurice J. Sullivan Family Hospice Center
912135 Old Fort Weaver Road	Kahi Mohala
601 Coral Street	Care Hawai‘i
Institutional—Medical/Diagnostic	
2043 Dillingham Boulevard	Blood Bank Hawai‘i
Institutional—University/Research	
96045 Ala‘ike Street	Leeward Community College
866 Dillingham Boulevard	Employment Training Center
881 Dillingham Boulevard	Employment Training Center
955 Kamehameha Highway	UH Mānoa Urban Garden Center
Dillingham Boulevard	Honolulu Community College
Military—Operations	
891 Valkenburgh Street	Branch 46 Fleet Reserve Association
Utility Station—Electric	
170 Ala Moana Boulevard	Hawaiian Electric Company
4292 Salt Lake Boulevard	Hawaiian Electric Company
2671 Mokumoa Street	Hawaiian Electric Company
Utility Station—Telephone	
94581 Farrington Highway	Hawaiian Telcom
98327 Kaamilo Street	Hawaiian Telcom
1928 Saratoga Avenue*	Hawaiian Telcom

*Planned extension

Disturbances to the existing static magnetic field from electric-propulsion currents are expected to have a frequency spectrum of 0 to 10 Hz and would occur at intervals determined by passing trains. The magnetic component of EMF produced by the Project is expected to be the most problematic in terms of interference with sensitive research measurements.

Table 5-1 contains a very preliminary prediction of magnetic field densities versus distance from the Project's centerline for light rail and rapid rail transit technology. These predications have been greatly simplified and only take into consideration the dipole moment created by the parallel paths of the supply and return currents. A dipole moment is a vector quantity that has both magnitude and direction. In the case of a current loop, the dipole moment is always in a plane perpendicular to the current paths.

These predictions are based on maximum current draw and assume that the current is coming from one substation (in reality the current will be split between adjacent substations). The magnetic field density (mG) values in Table 5-1 are all less than the values found in Table 2-1 (*ACGIH Guidelines for Occupational Exposure to 60-Hz EMF*). These mG values are all also less than the values in Table 2-2 (*Guidelines on Limits of Exposure to 50-60 Hz EMF*) expected in general public exposure at 15 feet. Due to the assumptions concerning the location of the traction power substations, further analysis of magnetic field exposure will occur after these locations are finalized.

Table 5-1: Preliminary Magnetic Field Prediction for Light Rail and Rapid Rail Transit Technologies

Technology	Max Current (amps)	Distance Between Current Paths	Magnetic Field Density (mG) at Distance			
			15 feet	50 feet	100 feet	200 feet
Light rail	3,600	4'-6¼"	475	43	11	3
Rapid rail	4,500	4'-6¼"	593	53	13	3

5.1 Effects on Sensitive Equipment

The Project's transit technology will be electrified and will thus create electromagnetic fields. However, at distances over 50 feet, these fields are of such low magnitude that the only potential effects would be on any instruments that may be in use within facilities adjacent to the right-of-way that are highly sensitive to any changes in the existing geomagnetic field. Table 5-2 provides examples of some of these instruments and their sensitivity levels. It can be seen that some of these instruments could be adversely affected as far away as 200 feet, depending on their orientation with the right-of-way. The calibration and/or operation of these instruments could be affected, not allowing them to perform as desired.

Table 5-2: Static Magnetic Field Threshold for Sensitive Instruments

Instrument	Static Field Change Threshold, mG
Research nuclear magnetic resonance spectrometers	0.5 (existing) 0.1 (future)
Research mass spectrometers	0.5
MRI (GE Medical Systems)	4 (10 @ 1 Hz, 40 @ 60 Hz)
Electron microscopes and X-ray analyzers (Hitachi and JEOL)	1 mG/5 min, (0.3 mG/5 min ac)[1]
Scanning electron microscope (FEI – Philips)	1 @ dc and other low frequencies (3 mG @ 60 Hz)

[1]Rate of change to the magnetic field over a 5-minute period at 60 Hz.
Source: Bracken 2001 (page 3).

Based on the results of the initial field survey to identify facilities potentially using some of these instruments, it was anticipated that one or more of the medical facilities found may use MRIs. Depending on the MRI's distance and orientation relative to the right-of-way, the operation of the instrument could be adversely affected.

Additional site visits and telephone calls conducted in September 2008 determined only one building within 200 feet of the proposed alignment centerline contains sensitive instruments. The Honolulu Community College has an electron microscope that would be between 200 and 250 feet from the alignment; however it would unlikely be affected by the Project. This will be confirmed during preliminary engineering.

5.2 Health Effects

A review of the state of the science regarding health effects associated with EMF found no new evidence linking EMF to biological issues at the levels and frequencies expected to be present from the Project. In June 2007, WHO released Fact Sheet No. 322, *Electromagnetic Fields and Public Health—Exposure to Extremely Low Frequency Fields* (WHO 2007a), which summarizes the findings of a task group WHO formed to review the health implications of these fields. As a result of their findings, WHO provided the following guidance:

> "For high-level short-term exposures to EMF, adverse health effects have been scientifically established (ICNIRP 2003). International exposure guidelines designed to protect workers and the public from these effects should be adopted by policy makers. EMF protection programs should include exposure measurements from sources where exposures might be expected to exceed limit values.
>
> Regarding long-term effects, given the weakness of the evidence for a link between exposure to ELF magnetic fields and childhood leukemia, the benefits of exposure reduction on health are unclear. In view of this situation, the following recommendations are given:

- Government and industry should monitor science and promote research programs to further reduce the uncertainty of the scientific evidence on the health effects of ELF field exposure. Through the ELF risk assessment process, gaps in knowledge have been identified, and these form the basis of a new research agenda.
- Member States are encouraged to establish effective and open communication programs with all stakeholders to enable informed decision-making. These may include improving coordination and consultation among industry, local government, and citizens in the planning process for ELF EMF-emitting facilities.
- When constructing new facilities and designing new equipment, including appliances, low-cost ways of reducing exposures may be explored. Appropriate exposure reduction measures will vary from one country to another. However, policies based on the adoption of arbitrary low exposure limits are not warranted."

Biological effects from acute exposure to magnetic fields well above the 1,000-mG level can be explained by recognized biophysical effects. Because the anticipated levels of the Project would be well below these levels, long-term effects on passengers and project workers would be inconsequential.

5.3 Effects of Existing Fields on Project Operations

As with all electrical apparatus, power transmission lines create electrical and magnetic fields. However, these transmission lines have a fixed frequency of 60 Hz, and the fields they create are well known. The existence of these lines in close proximity to the Project, such as along Dillingham Boulevard, can affect the proper functioning of some of the control and communication systems typically employed on transit projects. However, these systems can be designed and supplied so that they are compatible with these fields and will function safely within this environment.

6 Mitigation

Because no negative health effects related to EMF are anticipated from the Project, mitigation would not be required. However, where practical, prudent avoidance measures would be undertaken to limit EMF exposure. Prudent avoidance applied to EMFs suggests adopting measures to avoid EMF exposures when it is reasonable, practical, relatively inexpensive, and simple to do.

Systems design will consider existing EMF in the study corridor, and systems will be designed to be immune to these fields.

The electron microscope at Honolulu Community College is unlikely to be affected by the Project; however, this will be confirmed during preliminary engineering. If it is determined the electron microscope would be affected, measures would be evaluated to reduce EMF effects on the equipment.

Magnetic fields increase with the magnitude of the currents in the source and decrease with the distance away from the source. Thus, the primary mitigation methods would be to lower the electric currents or shift the proposed alignment to avoid placing sensitive facilities near the transit route. Often, these mitigation methods are not possible.

Aside from increased separation and reduced currents, the primary candidate for mitigation at receptor locations is placing high-permeability ferromagnetic "mu-metal" sheets in locations that shunt magnetic field lines away from sensitive areas. This approach can be facility-specific, undertaken after operation begins, and implemented on an as-needed basis. Magnetic shielding is a common approach already used by many facilities that conduct sensitive measurements in electrically noisy environments. Depending on the number of shielding layers used, attenuation factors of 10 to 200 can be achieved.

Another mitigation method involves electronic detection of the interfering field and generation of a canceling (i.e., opposing) magnetic field that counteracts the EMF/EMI at the location that must be protected from interference. This active electronic method has been used successfully in situations where power line fields have caused problems, but can be both expensive and maintenance-intensive.

In summary, an outline of mitigation methods follows:

- Reduce the effects of the source by making the source more distant
- Reduce the effects of the source by lowering electric currents in the source
- Reduce the effects of electric currents by making the circuitry more compact
- Cancel the effects of the source by creating magnetic fields in opposition to those produced by the source
- Shield the effects of the source by placing high-permeability "mu-metal" shielding in locations that shunt the magnetic field lines away from sensitive areas

Further investigation is needed to determine which of these options, or combination of options, might work best for EMI produced by the Project. Implementation of these options could be described as follows:

- The EMF effects of rail vehicles and electric power feeder lines could be reduced by moving the proposed route farther from sensitive buildings.
- The EMF effects of the electric power feeder lines could be reduced by bringing the individual conductors closer in a more compact configuration, so their mutually opposing currents would reduce the fields produced at a distance. An example of this would be adopting a third rail power distribution system rather than using an overhead contact system.
- EMF could be reduced by adding a second set of parallel conductors near the electric power feeder lines, but spaced an appropriate distance away from the existing set of conductors. The total current in the circuit could be split over these two sets of conductors, but the currents would be directed in a way that partially cancels the fields from the original set of conductors. This has been successfully conducted on two projects near affected facilities.
- A set of conductors could be placed near the outer walls of sensitive buildings and energized with current so that the fields produced by these added wires cancel the fields from the electric power feeder lines. The "slave" currents would have to be synchronized in phase and magnitude to the primary currents to produce magnetic fields that would mitigate the overall magnetic field effect.
- Magnetic shielding material could be added to the interior walls and floors of sensitive buildings to shunt magnetic field lines away from areas that require low ambient field levels. Shielding could also be used in a more localized manner to surround individual pieces of equipment.

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